Deltares

Phosphate adsorption and diffusion model into iron-coated sand grains

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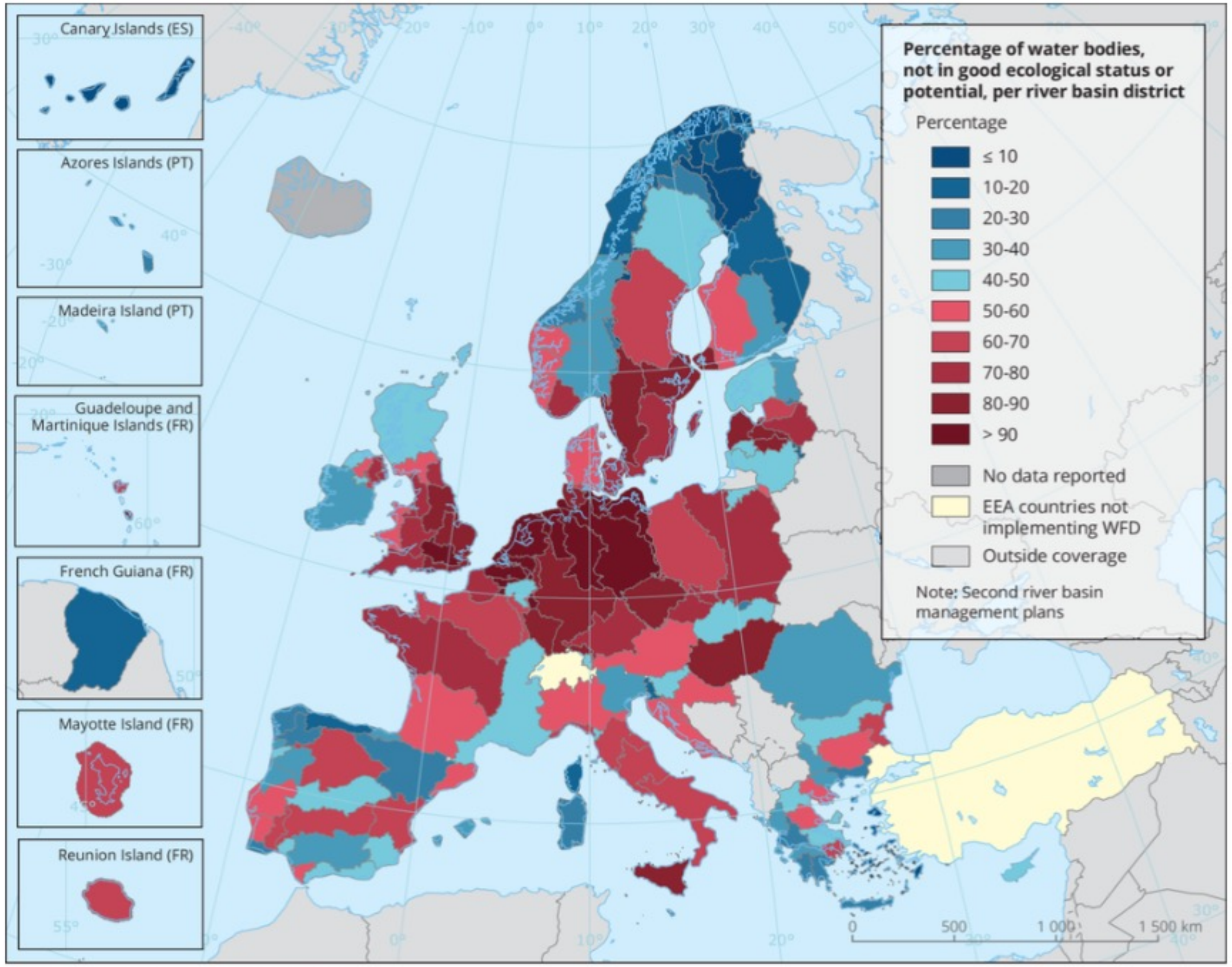
Water quality in rivers, lakes, and transition waters in Europe

60% of surface waters in the EU have less than good ecological status (WFD)

Most nutrients come from agriculture

P is a nutrient & may trigger algae growth



Reference data: ©ESRI | ©EuroGeographics

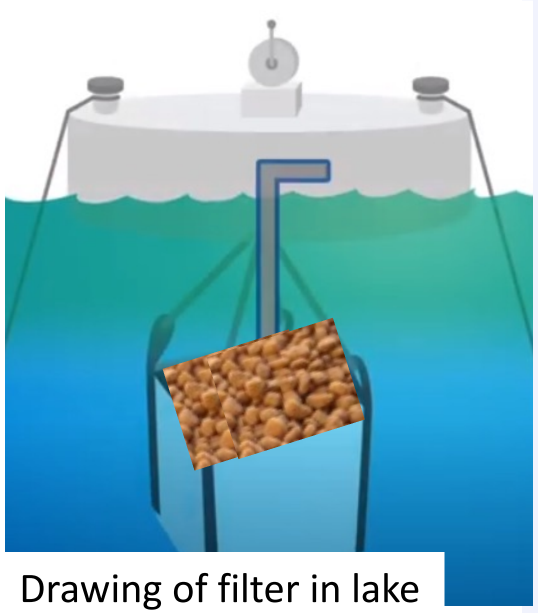
(EEA, 2021)

Deltares

Iron coated sand (ICS) filters

- Sustainable: by-product from drinking water
- **<u>High P retention</u>** capacity: adsorption potential of iron hydroxides
- Uses: around drains, out of drains box filter, in lakes, in retention basins outflow
- **<u>Has shown kinetic adsorption behavior</u>**
- Motivation: life-span, optimal flow velocity, stop-flow regime, maintenance

Construction filter around drainage



Drawing of filter in lake

ICS

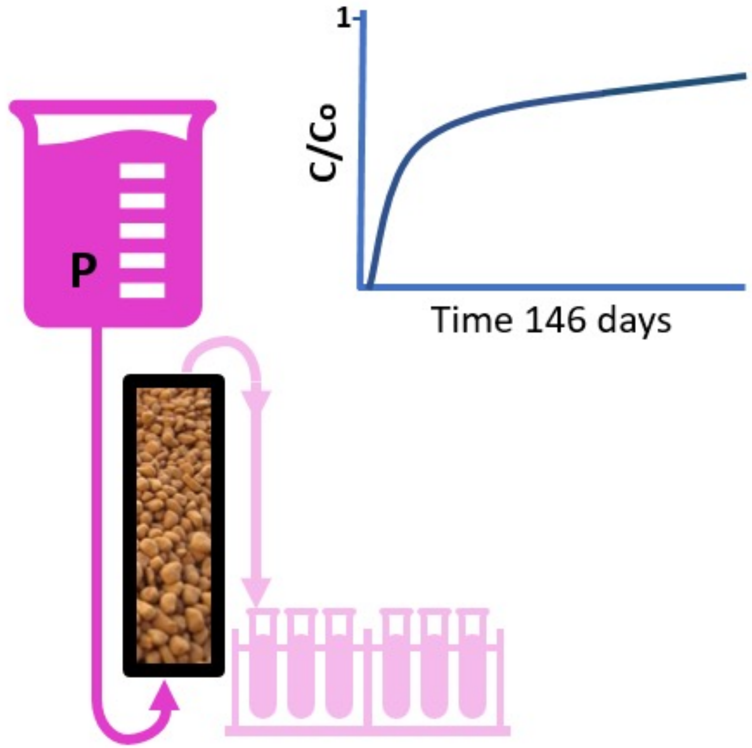
Filter in the outflow of a water retention basin

Methods

Laboratory setup

- Columns (3)
- Tracer tests and long term adsorption tests
- Constant flow, different velocities to evaluate kinetics
- Stop flow, to evaluate recovery time
- Microscopy (SEM-EDX) to see the inside of the grains

Column experiments



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Methods

Model

$$\underbrace{\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2} - \frac{v\partial c}{\partial x}}_{\text{Advection-Dispersion Equation}} - \underbrace{f\frac{\rho k}{\theta}\frac{\partial c}{\partial t}}_{\text{Adsorption in equilibrium } f \text{ sites}} - \underbrace{\frac{\rho\alpha}{\theta}(k(1-f)c - s)}_{\text{Adsorption not in equilibrium } 1-f \text{ sites}}$$

- The advection-dispersion equation of a solute adsorbed though a porous medium (1D).
- **Kinetics were represented in a 2-site model**

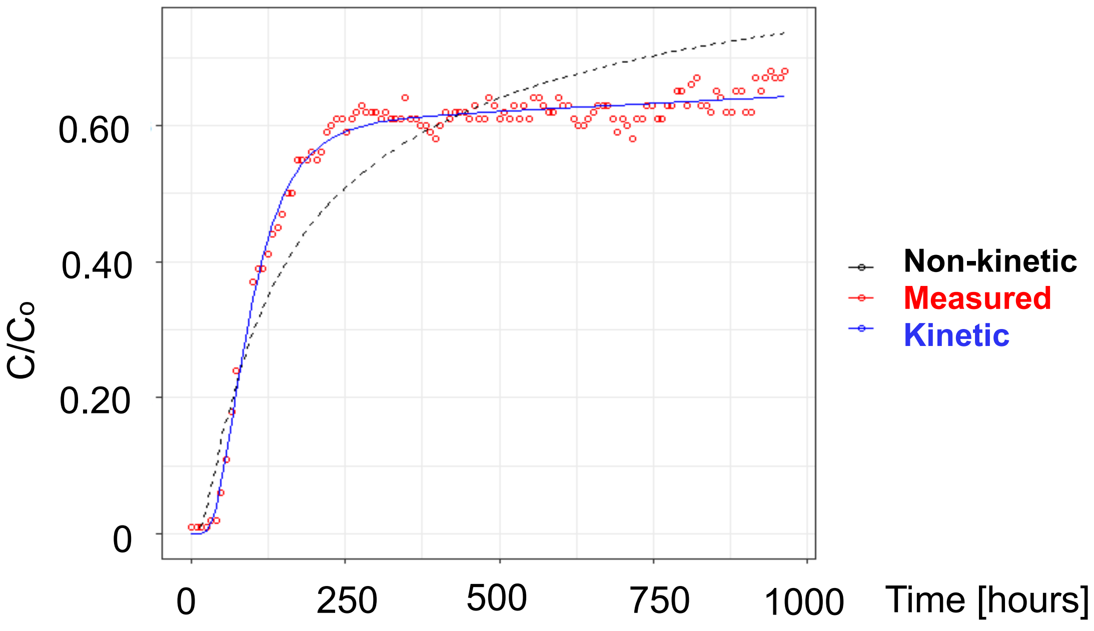
  Equilibrium sites (linear equilibrium, k) “fast adsorption”

  First order kinetics (mass transfer coef, α) “slow adsorption”.
- **Static solution and parameter fit** (D, α, k, *f*) : CXTFIT module (Toride et al., 1995) in Stanmod (Simunek et al., 1999; Van Genuchten et al., 2012), analytical solution.
- **Dynamic solution** ReacTran package in R (Soetaert and Petzoldt, 2020) using the previous parameters, 1D ode solver.

Results

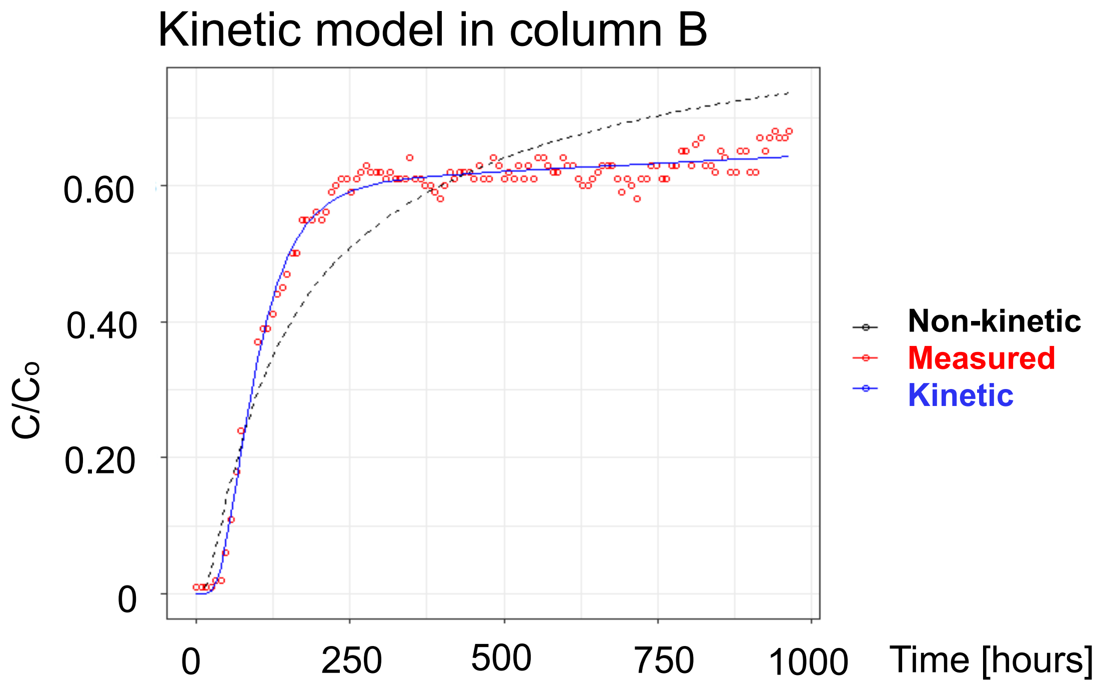
- Good fitting of non-equilibrium model, K = 28 L/g-Fe
- Maximum adsorption = K · C (mg/L)
- But, only 4% of sites are "fast" or in equilibrium
- <u>**The "slow" adsorption has the largest P retention capacity (96%)**</u>, α = 1.56 10^{-4}/h

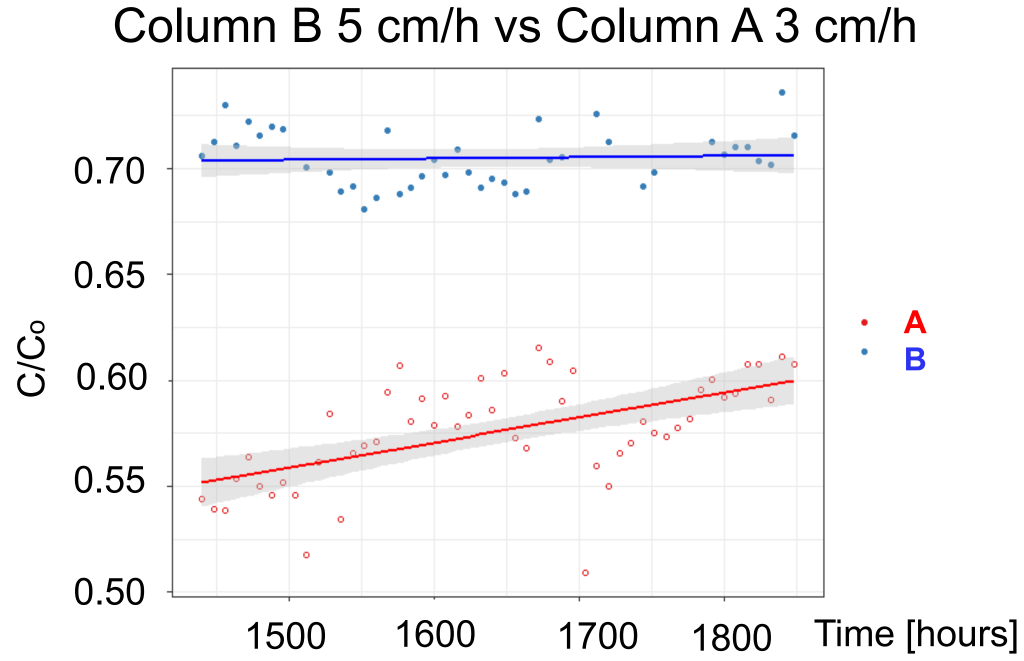
Kinetic model in column B



Results

- Good fitting of non-equilibrium model, K = 28 L/g-Fe
- Maximum adsorption = K · C (mg/L)
- But, only 4% of sites are "fast" or in equilibrium
- The "slow" adsorption has the largest P retention capacity (96%), α = 1.56 10^{-4}/h
- **Lower velocities increase the P retention**
- What if the flow stops?
- What does the "slow" and "fast" processes mean physically?

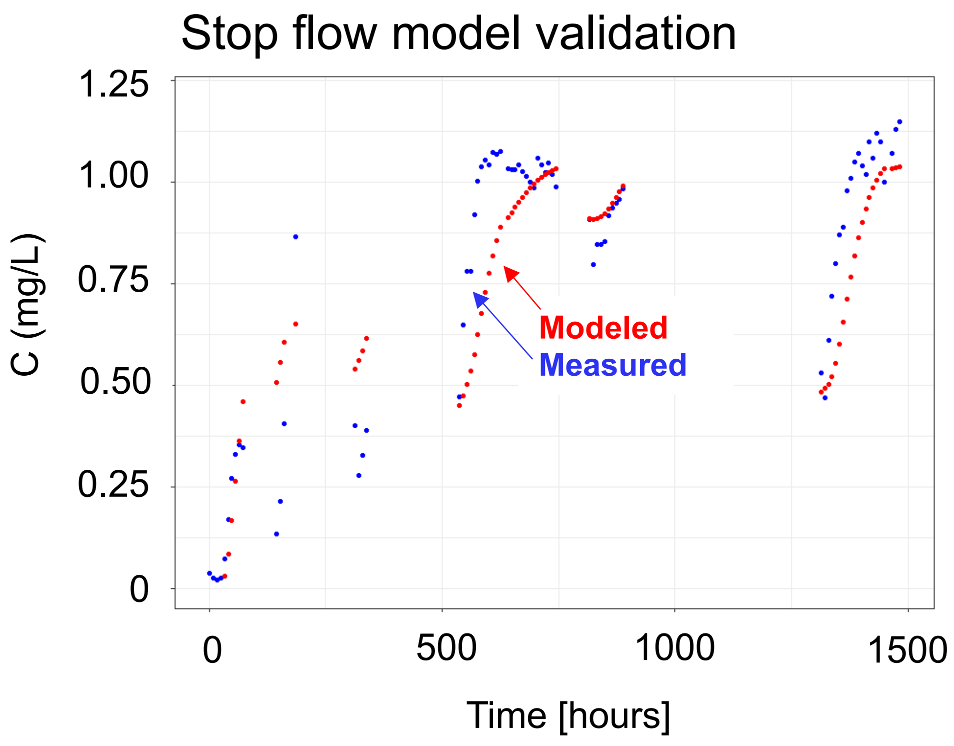




Results

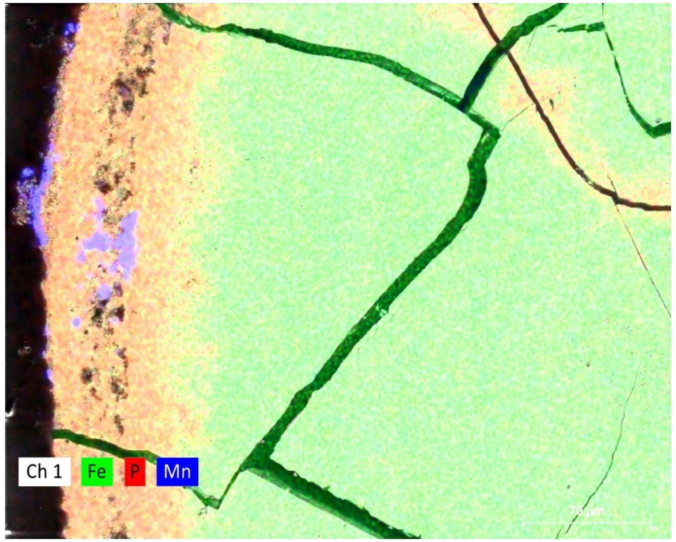
- **What if the flow stops?**
- The model can represent different velocities and stop-flow
- When the flow stops it gives time for mass transfer
- Some of the fast adsorption capacity is “recovered”

 Good for maintenance.

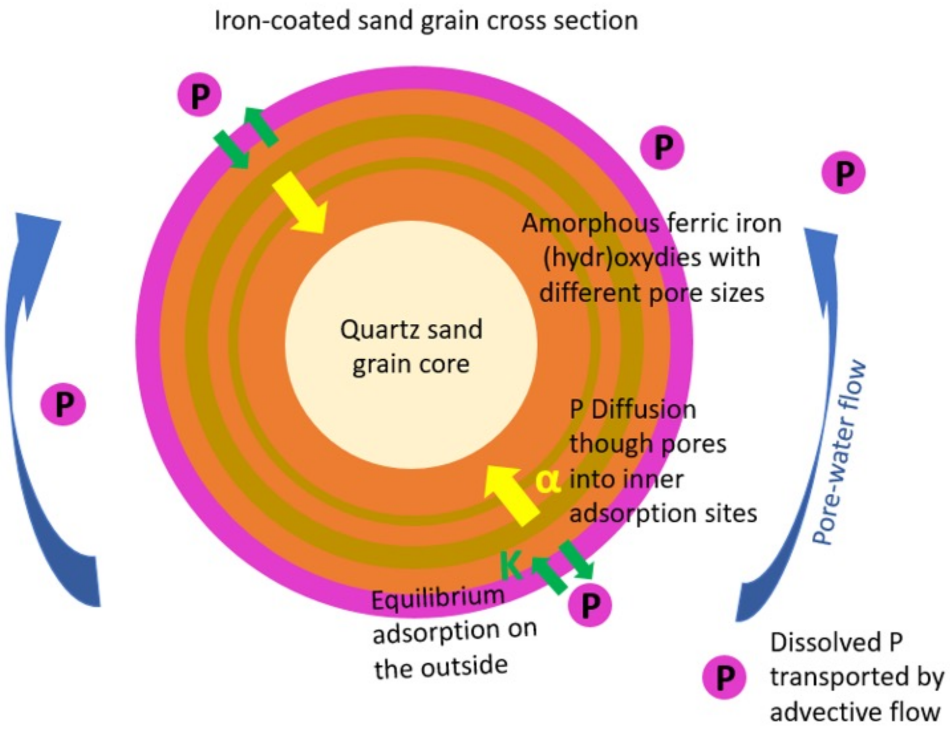


Results

- **<u>What do the "slow" and "fast" processes mean physically?</u>**
- The P transport to the adsorption sites inside the coating is limited by the micro-porosity of the coating (1-2 nm)



SEM-EDX image of ICS grain after adsorption



Conclusions

- The model can describe the mechanistic processes of P adsorption into ICS
- The model can be used for the design and operation of ICS filters
- ICS is a good and sustainable technology for natural systems with slow flow velocities
- Deltares and Arcadis are designing ICS filters

Thanks you!

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